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INTEGRATED USE OF ACOUSTICS AND TRAWLS TO ESTIMATE

STANDING STOCKS OF FORAGE FISH IN LAKE HURON

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ABSTRACT

This report describes the integrated use of acoustic methods with midwater and bottom trawling to estimate the size of pelagic and demersal stocks of alewives (Alosa pseudoharengus) and rainbow smelt (Osmerus mordax) in Lake Huron. The acoustic sampling system consisted of two 50 kHz echosounders coupled to either a transducer mounted on the hull of the ship or on the headline of the trawl. Fish abundance at middepths was estimated from echogram counts. The relation between echogram counts and midwater trawl catches was $Y = -2.69 + 0.983\ X$ with $r^2 = 0.766$ at the densities investigated. Estimates of demersal abundance were calculated from bottom trawl catches. Echogram counts and bottom trawl catches were not related. Standing stocks of alewives and smelt at middepths were estimated at 17,200 metric tons (t) in July 1974, 22,000 t in July 1975, and 19,000 t in August 1976. Estimates for the demersal component of the alewife-smelt forage stock, calculated from spring and fall bottom trawl catches (1973-77), ranged from 69,000 t during spring 1975 to 23,000 t in fall 1976. Estimates of the midwater stock, coinciding with the spring and fall bottom trawl surveys, indicated that about 22% of the total biomass was in midwater. I conclude that the combined acoustic-midwater and demersal surveys provide a far more realistic estimate of the standing stock than is possible by either type of survey alone.

INTRODUCTION

Design of the best strategy for rehabilitating game- and food-fish resources in the Great Lakes, as well as for managing the recreational and commercial fisheries they sustain, depends significantly on how accurately the size of the forage stocks can be determined. The forage stocks in Lake Huron are dominated by alewives (Alosa pseudoharengus) and rainbow smelt (Osmerus mordax), which together make up over 60% of the biomass available to bottom trawls. However, large numbers of alewives in the younger age groups and smaller numbers of smelt are pelagic and thus unavailable to bottom trawls (Wells 1968). Estimates of the proportion of alewives and smelt that make up the midwater biomass vary widely. Brown (1974), referring to alewives in Lake Michigan, indicated that the lake-wide biomass may be nearly 10 times that estimated on the basis of bottom trawling. Although this extrapolation may be high, the evidence is irrefutable that a sizable portion of the population is in midwater and cannot be sampled with conventional bottom trawling gear.

Although bottom trawls are useful tools for providing information on abundance, age, and species composition, they provide no information on the midwater stocks. Midwater trawls have the potential to provide information on the species and age composition of midwater stocks but require ancillary equipment to locate concentrations of fish that can be sampled. In addition, gear selectivity and escapement can only be crudely estimated and the area or volume that can be sampled is small, leading to large sampling variance; consequently midwater trawls are less than ideal for estimating abundance.

The use of hydroacoustic equipment to detect fish and estimate their abundance is gaining general acceptance as a reliable sampling method.

Acoustics provides the capability for rapidly surveying large expanses of water, and recent improvements in the design and capacity of equipment to rapidly process the enormous amounts of acoustic data make the technique increasingly attractive.

Acoustic techniques have been used extensively, and sometimes routinely, to estimate standing stocks of pelagic saltwater fishes--for example anchovies (Engraulis mordax) (Mais 1977); sockeye salmon (Oncorhynchus nerka) (Thorne and Dawson 1974); and Pacific hake (Merluccius productus) (Thorne, Reeves, and Milliken 1971). Also, many of the field research programs of the United Nations Development Program of FAO rely extensively on acoustic methods for estimating the size and yield of various pelagic fish resources (Johannesson and Losse 1977).

The use of acoustics for surveying freshwater fish stocks has received less attention, and has not been widely used in the Great Lakes. Kelso et al. (1974), using a digital echo-counting system, demonstrated the feasibility of using acoustic methods to estimate density of pelagic alewives and smelt. Kelso and Minns (1975) and Minns et al. (1978) used a modified system to determine fish distribution and density in relatively small, nearshore, shallow-water areas influenced by thermal discharges. Although these studies were conducted over only limited areas they demonstrated the applicability of acoustics for estimating pelagic fish stocks in the Great Lakes.

In this paper I report on the use of acoustic methods integrated with midwater and bottom trawling, to estimate standing stocks of forage fish in Lake Huron. The methods used and the results obtained are discussed, as well as some of the distributional characteristics of the alewife-smelt forage population.

SAMPLING METHODS

Alewives and smelt were sampled on the bottom and in midwater in Lake Huron with bottom and midwater trawls and acoustic scanning. Acoustics was used both as a separate sampling device and in conjunction with bottom and midwater trawls, to identify suitable trawling bottom, determine trawling depth, and to locate fish and estimate their abundance.

The U.S. waters of Lake Huron, excluding Saginaw Bay, were divided into four sectors (I-IV), each represented by at least one bottom trawling transect (Fig. 1). In addition to the sectors, I established reference points, each about 16 km from an adjacent point, to provide a means for planning the acoustic survey design, quickly estimating running time, and determining sampling location. Establishment of the sector boundaries was discretionary and the volume or surface area of water in each sector differed (Table 1). Nonetheless, I believe the sectors represent reasonable divisions of the lake that can be related to the trawl sampling.

Figure 1. Lake Huron, showing the sampling area, reference points, lake sectors used for the biomass calculations, and the locations of the bottom trawl survey transects mentioned in the text.

Table 1. Percent of total water volume of U.S. waters of Lake Huron (Saginaw Bay excluded) available to each sampling gear in different sectors of the lake. The volume of water available to bottom trawls includes all water within 2 m of the bottom; the remaining volume is considered available to acoustic scanning.

Lake sector[a]	Sampling transect [a]	Sampling method: Bottom trawl	Sampling method: Acoustic scanning
I	Hammond Bay & De Tour	37.3	58.7
II	Alpena	18.1	9.1
III	Au Sable Point	26.3	18.9
IV	Harbor Beach	18.3	13.3

[a]See Figure 1 for location of sectors and transects.

Bottom trawling, during early spring and late fall, was begun in 1973 along four transects off Hammond Bay, Alpena, Au Sable Point, and Harbor Beach (Fig. 1). An additional transect, off De Tour, was added in the fall of 1976 to supplement sampling in the northern part of the lake. Trawl tows in the standard series for any one transect, were made along the contour at depths of 9, 18, 27, 36, 46, 55, 64, 73, 91, and 110 m. Not all depths could be trawled along each transect, either because the bottom was too rough or because deep water was lacking; the depths not trawled were off De Tour 110 m, off Alpena 110 m, off Au Sable Point 91 and 110 m, and off Harbor Beach 9 and 110 m.

Midwater trawling and acoustic scanning surveys were conducted from late spring to early fall during 1974-76. Generally, three 8-day surveys were made each year.

Acoustic Sampling System

The acoustic sampling system consisted of two echo sounders, a Kelvin Hughes MS-44 and a Kelvin Hughes MS-29. The Kelvin Hughes MS-44 sounder was coupled to a 50 kHz hull mounted transducer having a rectangular beam angle of 12° (front to back) X 17° (abeam) at the standard half-power point (-3 dB). Recordings were on 21-cm dry chart paper with either gray or white-line bottom discrimination. A scale expander, usable in either bottom lock or midwater modes, provided three ranges of expansion (4.5, 9, or 18 m); this feature enabled a more detailed examination of fish concentrations than would otherwise be possible.

The duration of the sound pulse was 0.5 ms and the repetition rate 128 pulses per minute. This pulse duration theoretically allows for resolution between targets vertically spaced 37.5 cm apart. In practice, this degree of resolution would be attainable only if electronic displays were used. On chart paper recordings, it is impractical to assume that targets vertically separated by less than 1 m of water can be individually resolved. Therefore, I assumed that echo returns less than 3 mm long on the echograms represented a single fish.

Discrimination between single and multiple targets was based on the trace pattern. The shape and width of the trace is a function of the location of the fish relative to the acoustic axis, vessel speed, pulse repetition rate, paper speed, and depth. A stationary target in line with the acoustic axis along the vessel's track was represented on the chart as a crescent shaped trace. Fish lateral to the acoustic axis were represented by a trace pattern determined by the chord track. If the vertical trace exceeded 3 mm on the chart, I assumed that two or more targets were present. Schools of fish were avoided when the echogram counts were made because of the high variability between counts and catches associated with schools of fish. Multiple targets at the same distance from the sound source cannot be analyzed accurately on the paper echograms. Varying shades of gray can be discerned, but when signal saturation occurs, further increases in target strength (due to the presence of more fish) are not evident; this results in an underestimate of fish density. Underestimation becomes particularly severe in shallow depths, where the sampling volume is small and the location of the transducer on the hull precludes the detection of many fish near the surface. More detailed explanations of the problems and limitations associated with acoustic surveys have been published elsewhere--e.g., Cushing (1973) and Forbes and Nakken (1972).

A Kelvin Hughes MS-29 sounder, coupled to a 50 kHz headline transducer with a rectangular beam angle of 17° (front to back) X 25° (abeam) at -3dB, was used in conjunction with midwater trawl sampling. Signal coupling between the sounder and the transducer was by cable; pay out and retrieval were controlled by a constant tension winch. A switching arrangement permitted display of the signal from the headline or hull transducer on either of the sounders. Although the beam angle of the headline transducer was relatively wide (25°), less than 15% of the area of the net opening was scanned by the beam. Therefore the primary use of the headline system was to position the net in midwater, and not to estimate catch.

The volume of water scanned acoustically (V_s) was calculated using the relationship $\underline{V_s} = \tan \frac{\theta}{2} \, \underline{\bar{d}^2} \, \underline{L}$ where $\frac{\theta}{2}$ was one-half the beam angle at the half-pressure point (-3dB); $\underline{\bar{d}^2}$ was the square of the mean bottom depth along the vessel trackline; and $\underline{L}$ was the length of the trackline. Corrections for the volume not scanned near the apex of the sound cone due to the vessel speed and pulse repetition rate were usually small relative to the total volume scanned, e.g., the correction was less than 0.5% when the trawl was towed at 5.1 km/h at a depth of 50 m.

Fish density was calculated from serial sections of the echograms, which visually showed relative uniformity in depth and fish concentrations. The mean depth and distance traveled were determined for each section, then echo counts were made for a representative section which was usually about 12% of the echogram. The counts were expanded to include the total volume of water scanned and expressed as numbers/$10^4 m^3$. Biomass calculations were based on these density estimates and average weights of fish collected during midwater trawling.

Trawl sampling

Alewives and smelt were sampled at middepths with a light-weight nylon diamond-pattern midwater trawl having a 14.3-m headrope and footrope and a 13-mm mesh (stretched measure) cod end. Measurements made by scuba divers have shown that this trawl had an effective sampling area of 37.3 m^2 and opens vertically 5.5 m. During a 20-min tow at 5.1 km/h, the trawl strained 63,460 m^3 of water. Midwater tows usually lasted 20 min but some lasted as long as 60 min.

Samples of fish on or near the bottom were collected using a Yankee Standard No. 35 bottom trawl having a 12-m headrope, 15.5-m footrope, and a 13-mm mesh cod end. This trawl had an effective sampling area of 10.8 m^2 and opened vertically 2.2 m. During a standard 10-min tow at 4.6 km/h, the trawl strained 8,240 m^3 of water. Bottom trawl tows lasted 10 min except in several areas where bottom conditions limited them to 5 min. Catches during the shorter tows were adjusted to 10 min.

The acoustic equipment operated continuously during both midwater and bottom trawl surveys. Fish samples were collected in midwater whenever suitable numbers of fish were located acoustically. The depth fished by the trawl was determined from the echogram generated by the headline transducer and was controlled by altering the length of trawl cable in the water. The depths fished with the midwater trawl were most commonly between 20 and 50 m, and rarely exceeded 80 m. Alewives and smelt predominated in the midwater trawl catches, whereas bottom trawl catches were more diverse and included numerous bottom-dwelling species.

All trawl catches were sorted by species, counted, and weighed. Alewives and smelt were sorted by total length into adults and (depending on the season) into young-of-the-year or yearlings, and scale samples collected. Obtaining scale samples from alewives and smelt captured by the midwater trawls was frequently difficult because many scales were lost as a result of abrasion by the trawl during long tows.

Bottom trawl catches at each contour interval were summed individually by species, life stage, and mean weight; then expanded to include total volume available to the trawl in each contour. The individual contour volumes were then summed for each sector and the sectors totaled. Summation by contour interval reduces sampling bias because unusually large or small catches are weighted in proportion to the area available at that depth.

Estimates of the midwater population coincident with bottom trawling were calculated from the echograms generated during bottom trawl sampling. Targets between the trawl headrope and the lake bottom were not included in the counts.

Target counts were corrected for sampling volume, expanded to include total volume available to the acoustic gear, and summed by contour interval and sector.

RELATION BETWEEN ECHO COUNT AND MIDWATER TRAWL CATCH

I examined the relation between echogram counts and midwater trawl catches made simultaneously to verify the reasonableness of using echogram counts as an estimator of fish abundance in midwater. During 1974, a total of 29 midwater tows were made in water depths ranging from 18 to 75 m. The trawling (headrope) depth ranged from 5.5 to 47.7 m, depending on fish location. I accepted 21 of the tows for analysis, using three criteria for omitting tows (number omitted shown in parentheses): zero count and zero catch (2); occurrence of clusters of fish that could not be accurately counted on the echogram (5); or evidence that the trawl had been on the bottom, e.g., the occurrence of sculpins (Cottidae) in the catch (1).

Total catches in the 21 accepted trawl tows ranged from 7 to 411 fish (average, 116). Except for two bloaters (*Coregonus hoyi*) and one lake trout (*Salvelinus namaycush*), the total catch was composed of 66% smelt and 34% alewives. Tow times ranged from 10 to 30 min (average, 18.5 min). For this analysis, neither echo counts nor catches were adjusted to a fixed tow time.

During the calibration tows, the recorder speed was increased to 25.4 mm/min for the hull sounder and 11.4 mm/min for the headline sounder. The faster speeds simplified counting and increased count accuracy. The trawl path during the tow was plotted on the echogram generated by the hull transducer, and only targets within the vertical limits of the trawl opening were counted. Echogram counts were adjusted to compensate for beam pattern by equating sampling volume of the trawl with the theoretical sampling volume of the beam pattern at the trawling depth. Counts were adjusted upward at trawling depths shallower than 30 m and downward at deeper trawling depths.

The relation between adjusted echogram counts and trawl catch was $Y = -2.69 + 0.983\ X$ with $r^2 = 0.766$ ($n = 21$). The least squares (LS) regression equation indicates that echogram counts and trawl catches exhibit a high degree of linearity at the fish densities investigated (Fig. 2). The relation between the unadjusted echogram count data and the trawl catches was $Y = 47.95 + 0.520\ X$ with $r^2 = 0.530$ ($n = 21$). The LS regression equation calculated from the unadjusted data suggests that unadjusted echogram counts overestimate the trawl catch at low fish densities (<15 fish/ 10,000 m^3) and underestimate the trawl catch at higher densities (Fig. 2).

In addition to the probable error in the paper-count data, the question of midwater trawl efficiency must also be considered, because no trawl, midwater or bottom, is likely to be 100% efficient. Because the paper-count data as well as trawl catches are inherently variable, Geometric Mean (GM) Functional regressions were computed. The GM regressions for trawl catch on adjusted and unadjusted paper counts were $Y = -19.53 + 1.222\ X$ and $Y = 22.54 + 0.714\ X$, respectively (Fig. 2). Although neither equation was definitive, the GM

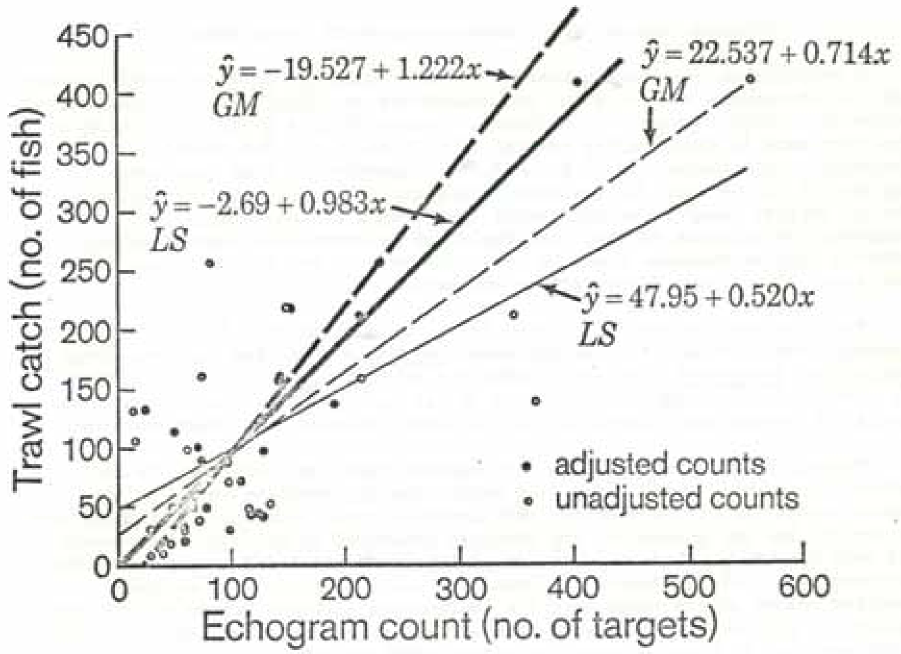

Figure 2. Relation between trawl catches and echogram counts. The adjusted counts correct the theoretical sampling volume of the beam pattern to match that of the trawl; where as the unadjusted counts represent actual counts from the echograms. GM = Geometric Mean functional regression; LS = Least Square Regression.

regression of trawl catch on adjusted paper counts appears to more closely approximate the anticipated 1:1 relation--at least at the relatively low fish densities sampled. Dowd (1967), using $\log_{10}$ transformed catch data ranging from about 10 to 1,000 fish per tow, showed a 1:1 relation between digital counts and trawl catches. If a tendency to overestimate trawl catch exists, as the GM regression based on adjusted counts suggests, the error would be of little significance. At higher densities, where multiple targets are common, the tendency to undercount becomes more pronounced. This tendency also exists, but to a lesser extent, when digital echo-counting is used (Kelso et al. 1974).

The obvious shortcoming of using the echogram counts to estimate midwater fish abundance is that accuracy varies with the density of fish. Expressing the counts and catches in terms of density (numbers per unit volume) the GM regression of trawl density (no. fish/100 m^3) on adjusted acoustic density most nearly approximated the anticipated 1:1 ratio (Fig. 3); where as the LS regression equation $\underline{Y} = 6.470 + 0.740\ \underline{X}$, calculated from the same data, underestimated the density of fish in the trawl. The present data suggest that extrapolation from the acoustic density is questionable beyond 70 counts/10,000 m^3--a catch rate for the midwater trawl roughly equivalent to 22 fish/min (Fig. 3).

STANDING STOCKS IN MIDWATER

The sizes of the standing stocks in midwater were estimated from acoustic surveys conducted during mid-July in 1974 and 1975 and mid-August in 1976. Although the survey course varied somewhat in the different years, the water volumes scanned and the distances traveled were similar. The depths scanned during the surveys ranged from 6.5 to 110 m and vessel speed, except while trawling was under way, was 16 km/h. Echogram counts and volumes scanned were grouped by bottom contour interval and expanded to include the total available volume in the interval. Estimates of the standing stocks were based on an average fish weight of 25 g; although the selection of this weight is somewhat arbitrary, it is a reasonable approximation based on numerous samples of midwater fishes examined over a period of several years.

On the basis of the survey data I estimated the standing stocks in midwater to be 17,200, 22,000, and 19,000 metric tons (t) during 1974, 1975, and 1976, respectively (Table 2). These estimates exclude all fish within 2 m of the bottom. Estimates of fish density and biomass at middepths were fairly consistent between years, particularly beyond the 10-m contour, where from 50 to 65% of the standing stock was located. In as much as estimates of fish density within the 0-10 m contour interval exceeded the upper limit of the range of values investigated during the coincident acoustic and trawl sampling, the biomass estimates may be too low.

The mean density estimates of forage fish at midwater depths, along contour intervals deeper than 10 m, were well within the range of values determined from coincident acoustic and trawl sampling. Also, the mean densities by contour, between years, were similar. This similarity is due, in part, to the large volume of water in the contour interval; however, it also

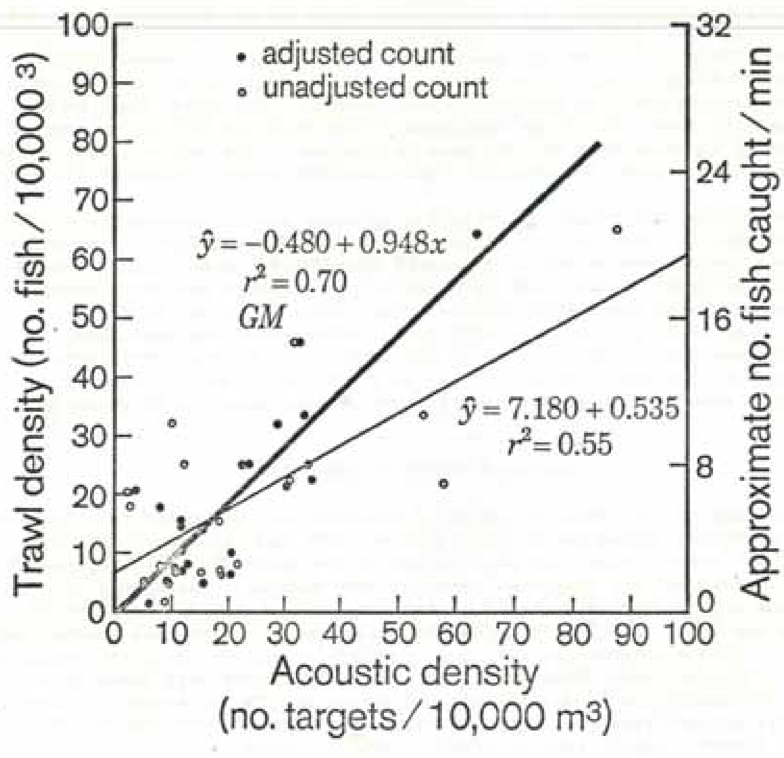

Figure 3. Relation between fish density (numbers/10,000 m^3) for acoustic and midwater trawl sampling. The adjusted counts were corrected to equalize the sampling volume of the beam pattern with that of the midwater trawl; the unadjusted counts represent actual counts from the echograms.

Table 2. Alewives and smelt in midwater in Lake Huron: biomass and mean density estimates, by depth contour, based on acoustic survey conducted during 1974, 1975, and 1976.

Contour interval (m)	Percent of total water withing contour Volume (m^3)	Area (m^2)	Percent of available contour volume sampled[a] 1974	1975	1976	Biomass (metric tons) 1974	1975	1976	Mean density (no./$10^4 m^3$) 1974	1975	1976
< 10	1.39	15.80	0.2	0.3	0.4	6,402	11,106	6,867	140.81	244.32	151.05
10-20	1.83	6.95	2.8	1.7	2.3	2,496	3,625	3,003	41.55	60.36	50.00
20-30	2.88	6.56	4.7	4.4	2.6	1,644	1,636	1,496	17.43	17.33	15.06
30-40	4.36	7.16	2.7	3.5	2.3	1,143	936	1,209	7.99	6.54	8.46
40-50	8.00	10.12	3.5	4.4	2.6	1,421	1,076	1,428	5.42	4.10	5.44
50-75	30.81	28.08	2.3	2.7	3.8	2,820	2,113	3,254	2.79	2.09	3.22
75-100	17.32	11.28	0.5	0.9	3.8	655	715	1,061	1.15	1.25	1.87
100-150	24.55	11.18	1.4	0.1	1.8	621	794	684	0.77	0.98	.85
150-200	0.32	2.71	0	0	0	-	-	-	-	-	-
> 200	0.54	1.15	0	0	0	-	-	-	-	-	-
TOTAL	100.00	100.00	1.9	1.9	3.0	17,202	22,001	19,002	5.66	5.61	4.29

[a]/Multiply figures by 10^{-2}.

attests to the reasonableness of the standing stock estimates. If the density estimates had been dissimilar, the data would be highly suspect because seasonal patterns of fish distribution would not be expected to change substantially between years. If mean density changes measurably over a period of years, the change should occur over all the deeper contour intervals and not be restricted to one or two. However, the shallow contour intervals (particularly 0 to 10-m) are exceptions because many young fish live in shallow water, and changes there might depend largely on the strengths of new year classes entering the population.

The changes observed in the standing stocks in midwater during 1974, 1975, and 1976 were consistent with changes in catch per unit of effort (CPE) and biomass calculated from spring and fall bottom trawl surveys for the same period (Table 3). Both sampling methods showed an increase in biomass during 1975, followed by a decline in 1976. The similarity in the results yielded by the two sampling methods, and the uniformity of the biomass and density estimates between years for the midwater sampling, suggest that the echogram counts provide a reasonable estimate of fish abundance--at least in deep water, where fish density is relatively low. However, the estimate must be considered relative because target strength was not determined. In addition, the inherent limitations of this system, including the lack of effective time-varied gain to compensate for geometric spreading of the sound pulse, make it virtually certain that the population is underestimated. Despite these limitations the system does provide an estimate of the magnitude of the midwater population and indicates that changes in abundance can be detected.

Table 3. Adult alewives and smelt in Lake Huron, 1974-76: catch per unit of effort and standing stock estimates based on spring and fall bottom trawling surveys. (Biomass estimates are rounded to the nearest 1000 metric tons.)

Season and year	Catch per unit of effort[a]		Biomass (metric tons)	
	Alewives	Smelt	Alewives	Smelt
Spring				
1974	144	187	17,000	9,000
1975	519	203	58,000	9,000
1976	93	277	12,000	16,000
Fall				
1974	61	249	9.000	17,000
1975	85	289	28,000	16,000
1976	44	361	10,000	12,000

[a]Unit of effort = 10-min trawl tow.

Table 4. Biomass estimates for demersal and pelagic distributions of alewives and smelt during spring (S) and fall (F) surveys conducted in Lake Huron in 1973-77. Estimates of the pelagic component were calculated from echograms generated coincident with bottom trawling; the midwater population was assumed to be 60% alewives and 40% smelt and the average weight of each fish, 25 g. Estimates of the demersal component were based on catches expanded by using the average weight, by life stage, of fish in the trawl. Biomass estimates were rounded to the nearest 100 metric tons.

Year and season		Biomass of demersal component (thousands of metric tons)							Biomass of midwater component (thousands of metric tons)		
		Alewives			Smelt			Total	Alewives	Smelt	Total
		Adults	Young of the year	Yearling	Adults	Young of the year	Yearling				
1973	S	9.5		1	13.5		1	23.2			
	F[a]	3.4	3		4.3	3		8.3			
1974	S	16.5		2.0	8.5		8	27.8			
	F	9.1	1.2		17.2	3		27.8			
1975	S	58.1		1.3	9.3		4	69.1			
	F	27.7	3.0		15.6	8		47.1	5.5	3.7	9.2
1976	S	12.0		4.3	15.5		8	32.7	7.3	4.8	12.1
	F	9.9	5		11.9	1.0		23.2	3.1	2.1	5.2
1977	S	30.5		1.9	10.5		1	43.0	15.7	10.5	26.2
	F	10.0	6.1		31.2	8		48.1	2.4	1.6	4.0

[a]The 1973 fall biomass estimate includes only sectors I and II (Fig. 1).

STANDING STOCK ESTIMATES BASED ON VISUAL GRADING

In addition to the July 1975 midwater survey described, midwater surveys were conducted during late May, late August, and early October of that year. Comparisons of fish abundance, between surveys, were based on visual grading. Although visual grading is subjective, it can be used with some success, provided the observer is consistent and remains unbiased (Forbes and Naken 1972).

Grading consisted of selecting serial portions of the echograms generated during both point-to-point surveys and surveys along transect lines perpendicular to the shoreline. In both surveys the echograms were stratified into 10-m depth strata and each stratum was assigned one of nine numerical grades on the basis of the apparent relative fish abundance. Each abundance estimate was considered a single observation. To ensure uniformity between surveys, I limited the number of observations between adjacent geographical reference points to one observation for each stratum present on each echogram generated (e.g., five observations would be made over a bottom depth of 50 m), whereas for transect surveys I initiated a new series of observations at each 10-m depth contour. The vessel track lines were similar for all the surveys except the one during August (explained later).

The number of observations varied among surveys: 376 observations for the May survey, 428 for July, 275 for August, and 493 for October. Nonetheless, the number of observations for each depth stratum, in terms of percent, were similar between surveys. Therefore, the numerical grades assigned were summed over all strata and divided by the total number of observations to yield a mean numerical estimate for each survey. A comparison of the numerical estimates thus obtained with the biomass calculated during the July survey (which served as a baseline) yielded the following standing stock estimates (sampling date in parentheses): 17,555 t (late May); 22,001 t (mid July); 32,100 t (late August); and 20,096 t (early October). Except for the late August survey, which was conducted almost entirely in the northern one-fourth of the lake, the estimates based on visual grading were reasonably close. If the August survey data are omitted the estimated mean standing stock in midwater was 19,884 t ($n = 3$, $SE = 1289$). The relatively close agreement between the midwater biomass estimates suggests that changes in abundance can be detected. The major drawbacks are the high degree of subjectivity in grading and the need for a baseline estimate.

RELATION BETWEEN ECHO COUNT IN THE PATH OF THE BOTTOM TRAWL AND CATCH

Echogram counts along the presumed path of the bottom trawl and the bottom trawl catch were unrelated. Fish near the bottom could be discerned but the number of fish present could not be reliably estimated. Detection of fish near the bottom is complicated by the presence of the strong bottom echo; consequently, vertical resolution is very poor. In addition, the geometry of the sound beam results in a sizable "dead field" near the bottom caused by the strong bottom echo generated when the leading edge of the spherical sound beam is tangent to the bottom. The strong return signal causes receiver saturation, and fish lateral to the tangent point and between the leading edge of the sound beam and the bottom cannot be separated from the bottom echo. Orr et al. (1978) who used high resolution equipment were unable to detect individual fish within 15 cm from the bottom. Although high resolution equipment may be useful for specialized surveys, species very near or on the bottom would not be detected. Also, large concentrations of fish near the bottom can reflect such a strong echo that it is not possible to distinguish between the fish and the true bottom.

INTEGRATED ACOUSTIC AND BOTTOM TRAWL SURVEYS

Standing stocks in midwater were estimated coincident with spring and fall bottom trawl surveys, beginning in fall 1975. Midwater estimates were based only on echo counts from targets located more than 2 m above the bottom, and the scanning volumes were decreased accordingly. The midwater counts per unit volume scanned were expanded by contour interval and summed over each of the four sectors. Biomass estimates were based on an average fish weight of 25 g. For the calculation, I assumed that alewives made up 60% of the midwater fish population--recognizing, however, that the proportion of alewives to smelt in midwater varies considerably and that ratio is undoubtedly affected by a number of factors, such as bottom type, topography, depth, temperature, and population density and age structure. Biomass estimates based on the bottom trawl catches were calculated as previously described.

Standing stock estimates of alewives and smelt at middepths varied between years (Table 4) as would be anticipated for species as dynamic as these. Whether the observed between-year changes in biomass, calculated for individual species, constitute real changes in the population is open to question. The 60-40 division is somewhat artificial and may bias the estimate toward one species. The combined estimate of alewives and smelt in midwater is more realistic in terms of changes in the population as a unit, and generally shows good agreement with biomass estimates derived from the bottom trawl catches. Biomass estimates of stocks in midwater were generally higher in the spring than in the fall. This difference probably reflects changes in distribution more strongly than changes in abundance over summer. The unusually high spring biomass estimate in 1977 may have been be due in part to the rapid rise in lake-wide temperatures, which was in sharp contrast to the slower warming pattern in spring 1976. The rapid warming trend prompted a mass movement of alewives shoreward, whereas in previous years this shoreward migration extended over a much longer period. Another possible explanation for the increase in abundance during 1977 is the entry of the very strong 1975 year class into the spawning stock. The CPE's and estimates for standing stocks on the bottom were also very high during the 1977 spring survey, suggesting that the population did increase.

Estimates of bottom stocks of alewives were also higher in the spring than in the fall surveys (Table 4). This pattern was consistent every year in 1973-77, with the possible exception of fall 1973 when only two transects were sampled. However, the limited data obtained suggest that the biomass during the fall of 1973 was smaller than that of the previous spring.

In 1975 the biomass estimate calculated from the spring survey data was inflated by two unusually large catches along the 30 to 40-m contour--one off Au Sable Point and one off Harbor Beach. The projected standing stock estimate of about 30,000 t of alewives, based on these two catches, was more than 100 times larger than that of other years. In 1977 the biomass estimate was also inflated, this time by one large catch off Alpena along the 30 to 40-m contour. This projected biomass estimate was over 13,000 t; by comparison the 1976 spring estimate was less than 1,000 t along the same contour.

Estimates of the standing stock of smelt available to the bottom trawls during the fall surveys were relatively consistent between years except for that of fall 1977, which was inflated by one unusually large catch off Hammond Bay (Table 4). the calculated estimate, based on this catch, was about 13,000 t--some 6 times the estimated abundance along the same contour in fall 1976 and 1975. Estimates in the fall were usually larger than those during the preceding spring when smelt were moving rapidly inshore to spawn in waters shallower than the vessel could occupy.

The combined alewife-smelt biomass estimates, calculated from the acoustic-midwater and bottom trawl surveys, ranged from 28,000 t during fall 1976 to 69,000 t during spring 1977 (Table 4). The acoustic estimates contributed between 7 and 38% ($\bar{x}$ = 22%) to the total biomass. Generally, the two sampling devices responded similarly to changes in the population. For example, the fall acoustic surveys indicated that abundance in midwater declined from 9,200 t in 1975 to 5,200 t in 1976 and was virtually unchanged, (4,000 t) in 1977. Biomass of adult alewives, calculated from the bottom trawl catches showed a similar trend (27,700, 9,900, and 10,000 t, respectively). The standing stock of smelt was about the same in 1975 and 1976 but increased sharply in 1977; however, the fall 1977 estimate appeared inflated by one very large catch, the removal of which would bring the estimate into line with that of previous and subsequent years.

The reason for the large differences in biomass between seasons is not clear. Wells (1968) also noted a decline in fall versus spring and summer bottom trawl catches of alewives and suggested that alewives may remain in midwater during summer and fall. Standing stock estimates, calculated from the July or August acoustic-midwater surveys during 1974, 1975, and 1976, showed that large numbers of fish were present in midwater during the summer. However, acoustic estimates made concurrently with the fall bottom trawl surveys did not indicate that large numbers of fish were at middepths. This discrepancy may suggest that additional surveys are needed to characterize the middepth population. Nevertheless, there is no doubt that combining pelagic with demersal improves the accuracy of estimates of the size of the standing stock.

CONCLUSIONS

Acoustic survey methods, used in conjunction with midwater and bottom trawls, provided considerable information on the size of the standing stock of alewives and smelt at middepths. Acoustic surveys indicated that the standing stock at middepths in summer was at least double that observed during the early spring or late fall. Generally, the population in midwater was smallest during the fall, showed a marked increase during the spring survey, and reached a peak during late summer. Bottom trawl surveys indicated that the demersal stocks were largest in spring, declined over summer, and were smallest in fall. The apparent decline among both the pelagic and demersal stocks, during the fall is probably due to changes in the distribution--which suggests that the fall midwater surveys may need to be more extensive.

Although there was a good relation between the echogram counts and the midwater trawl catches, the echogram counts do have some rather severe limitations. First, and perhaps foremost, is that the accuracy of the echogram count is highly dependent upon the density (number of fish per unit volume); as fish density increases beyond a certain point, the accuracy of the count decreases. Secondly, the use of the echogram counts to compute biomass necessitates relying on an average fish weight--a weight that may be incorrect and certainly changes with the season, location in the water column, or age structure of the population. Both of these limitations could be largely removed by using a digital data-acquisition system, which would enable the separation of echo returns into various signal strength and depth categories.

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